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MICROWAVE OVEN TEST LOAD EVALUATION and DETERMINATION of INTERNAL MICROWAVE ENERGY DISTRIBUTION

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MICROWAVE OVEN TEST LOAD EVALUATION and DETERMINATION of INTERNAL MICROWAVE ENERGY DISTRIBUTION

Harry Levine and Robert L. Moore

Product Testing and Evaluation Branch

Division of Electronic Products

August 1970

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
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Bureau of Radiological Health
Rockville, Maryland 20852

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John C. Villforth
Director
Bureau of Radiological Health

PREFACE

The Division of Electronic Products, Bureau of Radiological Health, as a part of its responsibility under the "Radiation Control for Health and Safety Act of 1968", is conducting a program to evaluate microwave oven test loads and the techniques for determining microwave energy distribution by chemical methods. This report describes the effect of load temperature, configuration, and suitability of loads other than water on leakage measurements for microwave ovens. Repeatability of leakage measurements and weight loss of various test loads as a function of heating time are also discussed. These studies are intended to include many major variables involved in any procedure for determining microwave oven radiation leakage.

Robert L. Elder, Sc.D.
Director
Division of Electronic Products

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ABSTRACT

A study was made to investigate the variables that must be considered in any test procedure used to measure radiation leakage from microwave ovens. An evaluation was made of the effect of various factors involved in such measurements, including load temperature, size and shape of containers for the load, water load repeatability, and the suitability of loads other than water. A study was also made of the distribution of microwave patterns in an oven using sponge substrate impregnated with hydrated cobaltous chloride. The chemically impregnated sponge test could be a very helpful aid in determining the test load position in order to create the condition of worst possible leakage from a microwave oven.

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MICROWAVE OVEN TEST LOAD EVALUATION AND DETERMINATION OF INTERNAL MICROWAVE ENERGY DISTRIBUTION

1. INTRODUCTION

The use of microwave energy in heating devices has recently caused increased interest and a greater awareness of the potential hazards to human health from exposure to electromagnetic radiation. The microwave ovens discussed in this study use frequencies of 915 MHz and 2450 MHz which are in the microwave range. When this radiation encounters polar molecules, a rotational relaxation occurs in which electromagnetic energy is strongly absorbed. Microwaves, as a source of power for a consumer product, are generally intended to be used in a completely enclosed space which allows no access while the microwave source is operating. Because some leakage does result, the Product Testing and Evaluation Branch of the Division of Electronic Products has been investigating certain variables that must be considered in any test procedure used to measure microwave radiation leakage. Present tests employ a test load consisting of 275 ml of water in a pyrex beaker placed in the center of the oven. The first portion of this report examines the suitability of this test load and evaluates the effect of various factors involved in testing leakage associated with microwave ovens, such as container configuration, load temperature, and reproducibility of results. This portion complements the report "Leakage Variations from Microwave Ovens" (1).

The second portion of the report deals with microwave energy distribution in an oven as demonstrated by sponge substrates impregnated with hydrated cobaltous chloride (2).

Both sections of this report deal with the same theoretical considerations concerning microwave energy within the cavity and its relation to leakage. When microwave energy is fed into the cavity of an oven, that energy must be dissipated or released in some way. If a load is present in the cavity, then some of the energy will enter the load and result in heat. Since it is highly unlikely that the load will be perfectly matched to the power source of the cavity and therefore absorb all the energy, some energy will then be reflected back to the source and a standing wave pattern will result in the cavity. If some other exit for energy is present, such as around the door edge, then the amount of this leakage energy will partly depend on the energy not absorbed by the load. By examining the absorption characteristics of the load, it should be possible to predict the relative leakage, assuming all additional factors remain constant.

The absorption of microwave energy is directly related to the dielectric constant of the material. A material of high dielectric

constant would absorb more energy and therefore result in less leakage. Since water is most often used as a test load for microwave ovens, its dielectric constant characteristics have been examined. It has been found that water has a very high dielectric constant which decreases as the temperature increases (3). By hypothesis the leakage should increase as the water load temperature increases. Correspondingly the more material of a particular dielectric constant present in the oven cavity, the more energy should be absorbed and, therefore, the lower the resultant leakage.

Practically, however, the standing wave pattern within the oven, the configuration of the load, and the load placement, along with the above mentioned factors, all play a part in determining the resultant leakage. In addition, the physical characteristics of the oven under test will also have a controlling influence on the leakage.

All leakage measurements presented in this study were made with the Narda 8100 Electromagnetic Radiation Survey Meter at a distance of 5 centimeters from the oven surface.

2. EXPERIMENTAL DATA

2.1 MICROWAVE OVEN TEST LOAD MEASUREMENT METHODS AND DATA

In order to compare leakage measurements resulting from different test load conditions, it was first necessary to determine the various characteristics of the water loads themselves. The results of the tests performed to determine the effects of load temperature and configuration on leakage and the repeatability of measurements are described below. All measurements were performed using the slow meter response and an average reading in order to obtain more repeatable results and fewer meter needle fluctuations. The microwave oven used in all tests was the Montgomery Ward Signature Model KTM 8090. The general procedure used for these tests is listed in appendix A.

2.1.1 Leakage Dependence on Water Load Temperature

If the leakage is measured at specific load temperatures as the oven is heating the load, then basically two variables can cause leakage level changes. The first is the load temperature, and the second is a change in magnetron output power as the unit is heated. The magnetron output power will generally decrease with an increase in operating temperature and thus mask any effect caused by a change in the load temperature. To avoid changes in leakage resulting from magnetron heating, the water was heated to a predetermined initial temperature before placement in the oven. The water load was then placed in the oven, and the oven was allowed to run for a predetermined amount of

time before a leakage reading was taken. Five replicate tests at each initial temperature were conducted with the initial temperatures ranging from 25°C to 95°C in 10°C increments. The procedure for these tests is listed in appendix A. Results of the average tests are shown in table 1.

2.1.2 Leakage Dependence on Load Temperature using Organic Liquids as the Load

Five replicate tests were performed first with 275 ml of ethylene glycol and again with 275 ml of glycerine. These organic liquids were chosen as test loads because they have high boiling points, are nonvolatile, nontoxic, and were readily available in the laboratory. The procedure used is exactly as described in the water-load temperature-dependence tests listed in appendix A. The temperature range extended from 25°C to 175°C in 10°C increments. Results of the average tests are shown in table 1.

2.1.3 Water Load Configuration and Repeatability Tests

Each series of tests was performed to determine the variation in leakage measurements resulting from identical tests in which the loads were placed visually rather than by exact measurement. To minimize magnetron output variability, the oven was shut off and allowed to cool between runs. The load was also allowed to cool between runs so that changes in initial load temperature would not be a factor. Each set of readings was taken after the same amount of on time. The load was removed from the oven between runs and then placed back as close as possible to the original position. The procedure for these tests is listed in appendix A.

Several of the above series of tests were performed to determine the dependence of leakage on the configuration of the container of water. The different containers were chosen because they were readily available in the laboratory. Five replicate tests were made on each configuration, and average values with standard deviations were calculated. Comparison of the average leakage values shows the effect of container configuration, and the relative magnitude of the standard deviation reveals the repeatability of the leakage readings. Results of these tests are shown in table 2.

2.1.4 Substrate Configuration and Repeatability Tests

Several different types of materials, both wet and dry, of varying shapes were tested for repeatability as described in the general procedure listed in appendix A. Glass wool and asbestos fiber configurations were formed by pressing the material to the desired shape. A lucite rectangle and cube were also used to contain the material desired as

Table 1. Effect of initial load temperature on leakage.

Instrumentation	Narda Meter 8110 s/n 02005 Probe Model 8121 s/n 02006		Narda Meter 8110 s/n 01023 Probe Model 8121 s/n 02006		Narda Meter 8110 s/n 01023 Probe Model 8121A s/n 02129	
Initial load temperature (°C)	Water load leakage[a] (mW/cm^2)		Ethylene glycol leakage[a] (mW/cm^2)		Glycerine leakage[a] (mW/cm^2)	
	Average	Standard deviation	Average	Standard deviation	Average	Standard deviation
25	1.20	0.04	1.11	0.10	1.02	0.09
35	1.14	0.07	0.98	0.10	1.00	0.14
45	1.19	0.07	0.94	0.09	1.04	0.04
55	1.14	0.13	1.00	0.07	0.97	0.06
65	1.07	0.13	0.83	0.04	1.09	0.12
75	1.04	0.16	0.82	0.04	1.04	0.11
85	1.02	0.16	0.77	0.03	1.00	0.06
95	0.95	0.23	0.83	0.08	1.00	0.09
105			0.80	0.07	0.98	0.14
115			0.76	0.07	0.99	0.10
125			0.71	0.04	0.89	0.10
135			0.73	0.08	0.92	0.12
145			0.70	0.07	0.88	0.04
155			0.70	0.07	0.95	0.27
165			0.92	0.12	0.91	0.15
175			0.92	0.10	0.97	0.09

[a]Average values of five tests.

Table 2. Leakage dependence on water load configuration and repeatability tests.

Instrumentation: Narda Meter 8110 s/n 02145
Probe Model 8121A s/n 02127

Configuration	Leakage[a] (mW/cm^2)	
	Average	Standard deviation
275 ml of water in three 3" dia. petri dishes centered in triangle with apex toward front of oven	0.46	0.01
275 ml of water in 600-ml straight-lip beaker	1.26	0.04
275 ml of water in 600-ml flared-lip beaker	1.32	0.09
275 ml of water in 1000-ml straight-lip beaker	0.96	0.04
275 ml of water in 500-ml Erlermeyer flask	1.50	0.07
275 ml of water in 500-ml pyrex centrifuge bottle	1.42	0.06
275 ml of water in 7-1/2" x 11-3/4" flat pyrex dish pan	0.36	0.01
275 ml of water in six 50-ml pyrex crucibles placed in double semicircle in center of oven	0.63	0.10

[a]Average values of five tests.

an oven test load. The material used in the lucite rectangle was a red-colored powder with the name of "Super-Stuff #406"® which forms a gel with water. It is miscible with water and is often used to simulate muscle tissue. It acts like a culture media and can be used as a phantom for microwave energy absorption. The gel that is formed retains its water content when enclosed in a covered container. Five replicate tests were performed on each material. Average values with standard deviations were calculated. Results are shown in table 3.

2.1.5 Loss in Weight of Various Test Loads used in Microwave Ovens

This series of tests was performed to determine the loss in weight of 275 ml of water in 600-ml beakers, Super-Stuff #406 gel in 275 ml of water enclosed in a lucite rectangle and covered with a lucite lid, and glass wool with 275 ml of water enclosed in a lucite cube and covered with a lucite lid. It was shown in previous experimental data that leakage levels depend on the volume of water in the test load (1). A more constant leakage level would be derived from a test load having a minimum weight loss due to heating.

The procedure used was to place the test load in the center of the cavity floor and operate the oven for the time indicated by table 4. The oven was then turned off for two minutes and the weight of the test load determined. The procedure was then repeated until the cumulative heating time of 270 seconds was reached. This mumulative heating time adequately illustrates the weight loss trends involved. Results are shown in table 4.

2.2 DETERMINATION OF DISTRIBUTION OF MICROWAVE PATTERNS IN OVENS

2.2.1 Discussion

The microwave energy distribution in an oven can be of importance in determining the maximum and minimum microwave energy absorption in a load. One possible method of determining this distribution is to use some chemical compound that changes color to varying degrees with varying amounts of heating. If the power density causing the local heating is a minimum, then little color change will be evident. If the power density is near a maximum, then a fairly drastic color change will occur. By examining these color patterns, it may then be possible to determine where a test load might be placed in the oven to absorb a minimum amount of power and thus create a maximum leakage. The opposite effect of creating a minimum leakage with a maximum absorbed power could also be predicted in this manner.

Table 3. Effect of type and shape of substrate on repeatability of leakage measurements.

Instrumentation: Narda Meter 8110, s/n 02145
Probe Model 8121A, s/n 02129

No.	Substrate	Shape	Dimension	Weight (gm)	Water content (ml)	Leakage (mW/cm^2)[c]	
						Average	Standard deviation
1	Glass wool	Rectangle	5"x2"x2"	35	Dry	3.0	0
2	Glass wool	Rectangle	5"x2"x2"	35	200	0.96	0.21
3	Asbestos fiber	Cylinder	2" diameter 4" height	75	125	1.0	0.16
4	Glass wool	Flat Cylinder	4 3/8"-diameter 2 1/4"-height	75	275	0.46	0.12
5	Asbestos fiber	Cylinder	2"-diameter 2 1/4" height	30	75	0.66	0.07
6	Asbestos fiber	Cylinder	2"-diameter 3 1/2" height	70	Dry	1.2	0.25
7	Asbestos fiber	Cylinder	2"-diameter 3 1/2" height	70	215	1.1	0.22
8	Asbestos fiber	Cylinder	2"-diameter 2"-height	30	Dry	3.2	0.59
9	Asbestos fiber	Cylinder	2"-diameter 2"-height	30	90	0.85	0.12
10	Polystyrene	Rectangle	6"x2"x1"	15	Dry	2.1	0.22
11	Polystyrene	Rectangle	2 3/4"x2 3/4"x 2 3/4"	22	Dry	2.2	0.27
12	Glass wool	Cube[a]	3 1/2"x3 1/2"x 3 1/2"	120	275	0.93	0.03
13	Super-Stuff gel	Rectangle[b]	5 1/2"x3 1/2"x 1 1/2"	35	275	0.73	0.03

[a]Lucite cube containing glass wool impregnated with water and covered with lucite lid fastened with nylon screws.

[b]Lucite rectangle containing the gel and covered with lucite lid fastened with nylon screws.

[c]Average values of five tests.

Table 4. Percentage weight loss as a function of heating time for selected test loads.

Heating time (seconds)	Weight loss (percent)		
	Water	Super Stuff	Glass wool
30	0	0	0
90	0.4	0	0
150	1.1	0	0
210	6.0	0.6	2.7
270	11.1	1.2	5.2

Initial weight of water = 275 gm.

Initial weight of Super Stuff gel + water = 322 gm.

Initial weight of glass wool + water = 346 gm.

2.2.2 Procedure

The chemical compound used to observe the color phenomenon was hydrated cobaltous chloride ($CoCl_2 \cdot 6H_2O$). This material is reddish-pink when dissolved in water and when partially or completely dehydrated will become deep blue. Most cobaltous compounds are red when hydrated or in solution ($Co(H_2O)_6^{2+}$) and blue when dehydrated. The substrate used was a synthetic cellulose sponge chosen for uniformity, absorption, and resistance to wear. Five sponges were used for the test; each measured 16.0 cm by 9.0 cm by 0.7 cm. The sponges were placed on edge with the centers 3 cm apart, parallel to each other as shown in figure 1. The substrate support was made of a dense nonexpandable polystyrene which is fairly transparent to microwave energy. The sponges were placed in each oven in two positions. In one position the substrate holder was placed inside the oven parallel to the oven door, and in the other it was placed perpendicular to the oven door. A 0.3 M solution of hydrated cobaltous chloride was used to impregnate the sponges. Approximately 50 ml of the solution was absorbed by each sponge prior to irradiation in the oven. The oven was allowed to operate until dehydration took place, as indicated by the disappearance of the pink coloration of the sponges. This process occurred in about five minutes, depending on oven output power. The sponges were then removed from the oven, displayed in a holder, and photographed from two positions. Color Polaroid® film was used to record the pattern.

2.2.3 Characteristics of Microwaves

Since most metals approximate a perfect conductor for microwaves and since a perfect conductor is also a perfect reflector, then essentially all the incident microwave energy is reflected from the metal surfaces of the oven. When a source of microwave power is directed toward a metallic surface, some standing wave pattern results. This pattern has characteristic maxima and minima energy densities, and the patterns can be altered by changing the separation between source and metallic reflector. The standing wave patterns which occur in a microwave oven are a composite of the patterns which result from a source-metal reflector combination and parallel metal-metal reflectors. In many ovens a mechanism called a stirrer is employed to reflect the microwave energy entering the cavity by varying angles in order to move the standing wave pattern around in the oven. This results in more uniform heating of a substance placed within the cavity. If the standing wave pattern can be determined, then it may be possible to place a load within the cavity so that a minimum amount of energy is absorbed by the load. The energy not absorbed must either be reflected back into the source or escape from the cavity as leakage. Whether or not it escapes as leakage will depend on the particular pattern in the

oven when the load is present and also on the size of slots present. Since the sponges are impregnated with a substantial amount of reagent, they essentially act as a load for the oven. It would be useful to know whether the load placed in the cavity alters the microwave pattern. Experimental evidence indicates that the patterns are altered depending on the absorbing and reflecting qualities of the load, the quantity of the load, and the angle of incidence of the microwave energy (4). The degree of change in the microwave pattern has not been investigated and is subject to further research.

2.2.4 Experimental Results

The photographed microwave patterns of the sponges were used to determine power density extremes within the oven. Figures 2 through 8 illustrate typical sponge patterns produced by the microwave energy within the several oven cavities tested. Coded numbers on the photographs indicate their position in the oven cavity. An explanation of these codes is as follows: "S-S" means side to side position, and "F-B" means front to back position. "Low" means the substrate configuration shown in figure 1. The "high" configuration is not shown in these photographs. Load location designations specify the position of sponge number 1. The standard load of 275 ml of water in a 600-ml beaker was placed at each of the maxima and minima, and the corresponding leakage was measured with a Narda Model 8100. Data for seven microwave ovens are presented in table 5.

Table 5. Leakage as a function of position, determined by relative sponge color intensity.

Instrumentation: Narda Meter 8110, s/n 02145
Probe Model 8121, 2/n 02129

Load: 275 ml water in 600-ml beaker

Oven	Load location[b]	Relative sponge color intensity[c]	Leakage (mW/cm^2)
Magic Chef	10.0 cm R-11.5 cm F	Light	4.5
	18.0 cm R- 4.5 cm F	Medium-light	2.0
	12.0 cm R- 4.5 cm F	Medium-light	2.0
	9.0 cm R-17.0 cm F	Medium-light	2.0
	16.5 cm R-11.5 cm F	Dark	1.0
	21.0 cm R-20.0 cm F	Dark	1.0
Omnivend	7.5 cm R- 7.5 cm F	Light	1.1[d]
	5.0 cm R-18.0 cm F	Dark	1.7[d]
Montgomery Ward	19.0 cm R-16.0 cm F	Light	1.4[d]
	15.0 cm R-10.0 cm F	Dark	1.1[d]
Garland	22.0 cm R-15.0 cm F	Light	0.25[d]
	22.0 cm R-20.0 cm F	Light	0.50
	18.0 cm R-11.0 cm F	Dark	0.55
	28.0 cm R-13.0 cm F	Medium-dark	0.40
Sears	22.0 cm R-18.0 cm F	Light	0.03
	27.0 cm R-17.0 cm F	Dark	0.02
	15.0 cm R-15.0 cm F	Dark	0.01
Toshiba	16.0 cm R-18.0 cm F	Light	0.65
	23.0 cm R-18.0 cm F	Dark	0.68
	11.0 cm R- 6.0 cm F	Dark	1.2
General Electric[a]	10.0 cm Radius	Light	2.0
	Center	Light	1.9
	16.0 cm Radius	Dark	0.8

[a] General Electric uses a rotating round table on which the load is placed.

[b] Nomenclature: X cm R = X cm from the right side wall of oven cavity
Y cm F = Y cm from the front edge of oven cavity
X and Y locate center position of beaker

[c] Light indicates minimum absorption, dark indicates maximum absorption.

[d] Average of two runs.

3. CONCLUSIONS

3.1 TEST LOAD EVALUATION

Contrary to theoretical considerations discussed in the introduction, the leakage, as shown in table 1, decreases as the water load temperature increases. A possible contributing factor to this phenomenon is that the water is expanding and water vapor is given off as the load temperature increases, resulting in greater total surface area at the higher temperatures. This greater surface area reduces the absorption depth effect so that more water molecules are subjected to higher energy densities, resulting in more absorption with less leakage. The ethylene glycol and glycerine tests also followed the same general trend over most of their temperature range but reversed the process at the higher temperatures. Perhaps the change in surface area at those higher temperatures is not as great and the effect of the change in dielectric constant becomes more significant. Two reasons against the use of ethylene glycol and glycerine as test loads are (1) the vapors form a thick film on the interior oven surfaces at higher temperatures, and (2) the extremely high temperature attained by the beaker creates a handling problem on removal from the oven.

The results shown in table 2 reveal considerable variation in leakage for the same amount of water load depending on the configuration of the container. Assuming that the volume remains constant, it can be concluded that the leakage is directly related to the height of the water level. The higher the column of water and, consequently, the smaller the horizontal surface area, the higher the resultant leakage. Conversely, the lower the column of water and the larger the horizontal surface area, the smaller the leakage. This relationship may be true only for ovens that have the microwave power fed into the top of the cavity.

An examination of the standard deviations in table 3 shows that dry glass wool (test load 1), water-impregnated glass wool in a lucite container (test load 12), and Super-Stuff #406 in a lucite container (test load 13) yield the most repeatable leakage readings. Test load 1, however, cannot be considered as an adequate load for most microwave ovens, since it contains no water and, therefore, very little microwave absorption capabilities.

The advantage of using Super-Stuff #406 in a lucite container (test load 13) or water-impregnated glass wool in a lucite container (test load 12) as opposed to the standard test load of 275 ml of water in 600-ml beaker is that less weight loss occurs with heating as shown in table 4. Therefore, in situations where water loss is a significant

factor, these two test loads would be superior. An example of their potential use in the laboratory would be in life testing of microwave ovens where long ontimes are encountered.

3.2 MICROWAVE ENERGY PATTERN DETERMINATIONS

In the majority of ovens tested, less leakage was found when the load was placed at an energy maximum than when the load was placed at a minimum. When examining the test results, it is important that comparisons be made only between tests performed on the same oven, since leakage characteristics vary from oven to oven. In some instances it may be desirable to determine the test load position in order to create the condition of worst possible leakage from a microwave oven. The chemically impregnated sponge test would be very helpful in determining this position. Since the sponges have the ability to indicate high and low microwave intensity regions, such tests may also help the designer of an oven to create a uniform energy distribution. Microwave energy leakage could also be observed if a substrate impregnated with hydrated cobaltous chloride solution is placed near the edge of the oven door so that the leakage would cause a change in color. Preliminary tests indicate a sensitivity of approximately 10 mW/cm^2 if used for 5 minutes. This could be used as an inexpensive indicator of microwave leakage.

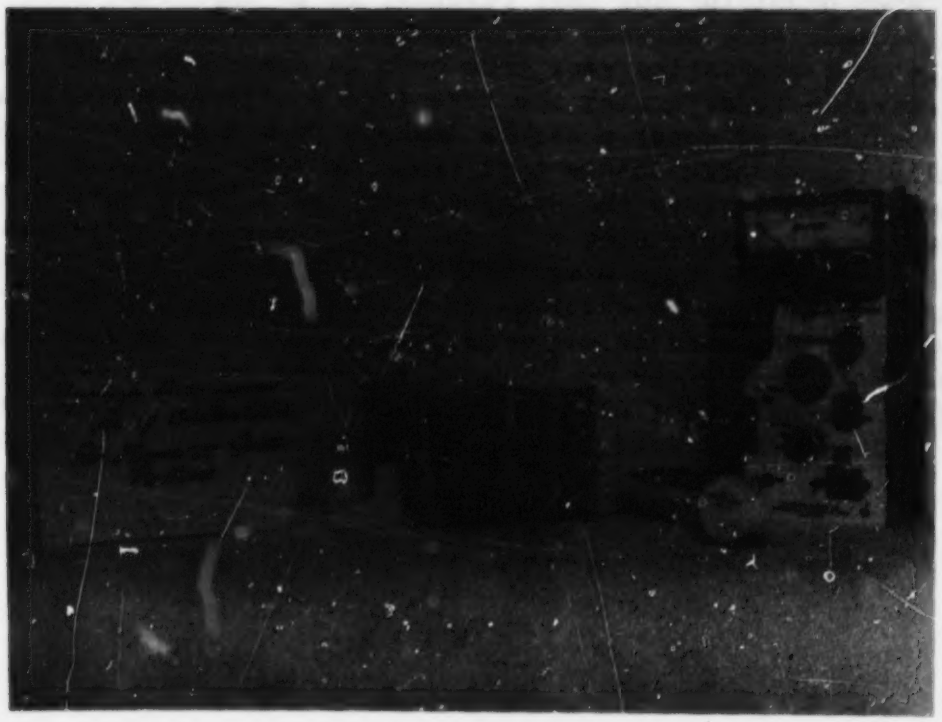

Figure 1. Narda 8100 Survey Meter and sponge arrangement on substrate holder as used in microwave ovens.

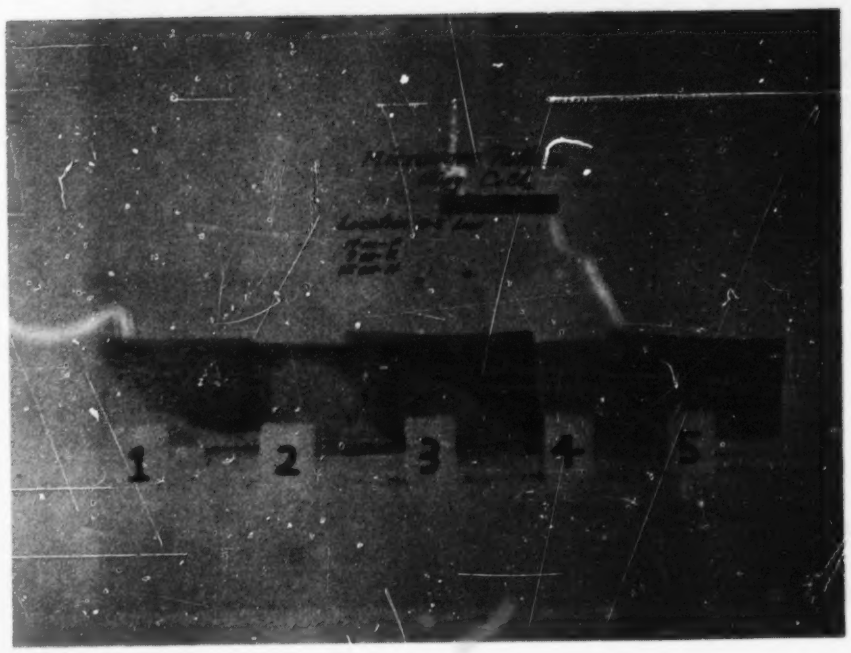

Figure 2. Typical sponge pattern showing energy distribution from Magic Chef® oven -- Model No. MC-75.01.

Figure 3. Typical sponge pattern showing energy distribution from Omnivend oven -- Model No. 110D.

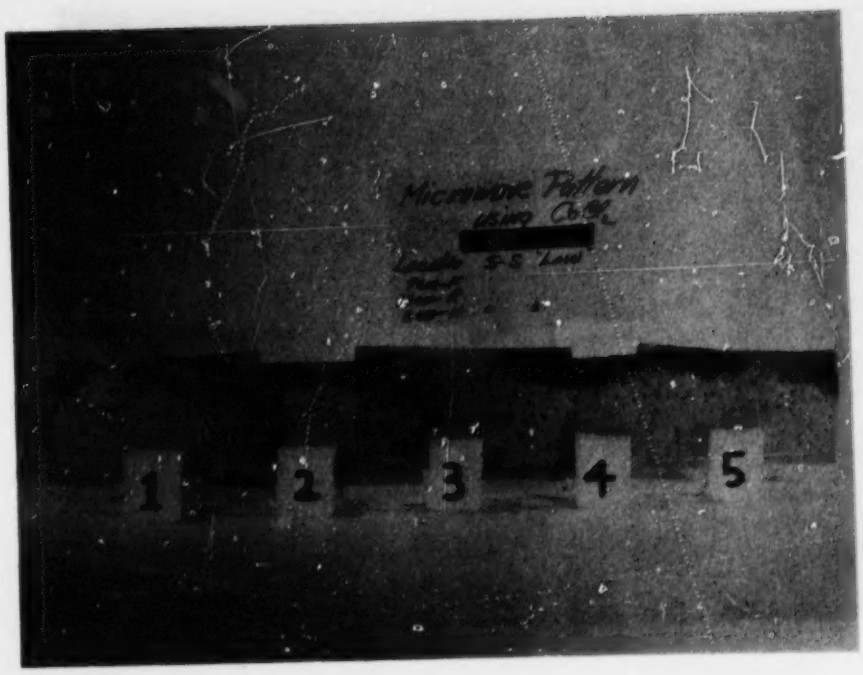

Figure 4. Typical sponge pattern showing energy distribution from Montgomery Ward oven -- Model No. KTM8090.

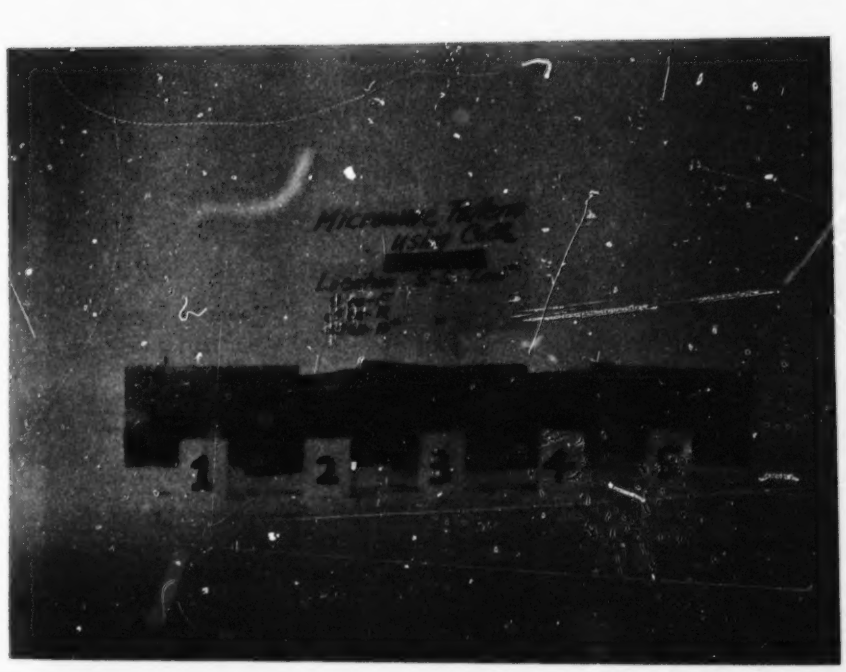

Figure 5. Typical sponge pattern showing energy distribution from Garland oven -- Model No. EM-1.

Figure 6. Typical sponge pattern showing energy distribution from Sears oven -- Model No. 103.9927001.

Figure 7. Typical sponge pattern showing energy distribution from Toshiba oven -- Model No. ER-602B.

Figure 8. Typical sponge pattern showing energy distribution from General Electric oven -- Model No. JE896E1.

REFERENCES

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(2) NAVAL FACILITIES ENGINEERING COMMAND, Proposed Federal Specifications for Oven, High Speed, Microwave, Electric S-O-1425. P. 4.4.2 "Microwave Distribution" (April 1969).

(3) HARVEY, A. F., Microwave Engineering. Academic Press Inc., N.Y., N.Y. (1963) 248-249.

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APPENDIX A
TEST PROCEDURES

General Procedure

1. A test load was placed on center of oven cavity floor and door was closed.
2. Oven was operated normally for 30 seconds.
3. Leakage was measured along right edge of door during the 30-second interval to obtain maximum reading position and record reading.
4. Test load was removed from oven and the oven was allowed to cool for two minutes.
5. The same probe orientation was used for each additional run.

Leakage Dependence on Water Load Temperature

1. Added 275 ml water to 600-ml beaker and brought to initial temperature externally.
2. Performed steps 1-5 inclusive of General Procedure.
3. Repeated steps 1-2 for next initial temperature.

Leakage Dependence on Water Load Configuration

1. Added 275 ml water at 25°C to configuration.
2. Performed steps 1-5 of General Procedure.
3. Repeated steps 1-2 for each configuration.

Water Load Repeatability

1. Added 275 ml water at 25°C to 600-ml beaker.
2. Performed steps 1-5 of General Procedure.
3. Repeated steps 1-2 for additional runs and used visual judgment to center the beaker.

DIVISION OF ELECTRONIC PRODUCTS

List of Publications

(continued from inside of front cover)

	Title	
BRH/DEP 70-8	Development of Liquid Crystal Microwave Power Density Meter (May 1970)	PB 191 396
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